APPROACHING SIX SIGMA QUALITY IN NUCLEAR FUEL FABRICATION – AN INDIAN PERSPECTIVE

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ABSTRACT

Nuclear Fuel complex, (NFC), Hyderabad, manufactures fuel and structural components for both Boiling Water Reactors (BWR) and Pressurised Heavy water (PHWR). Customer and product quality has always been assigned top priority at NFC. At present, NFC is pursuing the goal of attaining six sigma quality levels, the paper brings out the details of various steps initiated and progress made towards the same, with a special reference to end closure welds.

1.0 INTRODUCTION

Nuclear Fuel Complex, (NFC), Hyderabad, a constituent of the Department of Atomic Energy, manufactures fuel and structural components for the nuclear power reactors in India. Customer and Quality have always received topmost priority at NFC.

During early seventies and eighties, quality was ensured by inspection and quality control techniques. At intermediate stages, various destructive tests and non-destructive tests were carried out. The important process parameters were monitored by using control charts. In late eighties, apart from avoiding defectives, it became essential to provide overall assurance to the customer, that the product had met all the quality requirements. Thus, the quality policy was revised incorporating the following objectives.

" ... a policy of total quality encompassing all stages of production including the vendor qualification. It shall also assure the desired levels of conformance to international standard, and to keep abreast of all quality related improvements and implement them in the process appropriately."

2.0 NEED FOR SIX SIGMA

Sigma is a statistical term, which is used to represent variations from the mean. A large value of sigma indicates larger variations. In order to keep the rejections under control, it is essential to centre the process and minimise the sigma.

Six sigma is used to describe a state of "zero defects" operation that is possible to attain in reality. In quantitative terms, it can be translated into a maximum of 3.4 defects for every million operations [1,2]. Today, six sigma is considered as a bench mark for world class operations. 'Right first time and every time' forms the core of the philosophy.

Implementation of six sigma provides enormous cost benefits. It has been reported that it can bring down quality related costs by almost 15- 20 % for a three sigma company [2]. Consumption of various resources is brought down due to lower rejections rates. Lesser effluents are generated when rejections are low. In addition, implementation of six sigma provides several intangible benefits among which customer satisfaction being the foremost. It also fosters improved work culture.

3.0 APPROACH TO SIX SIGMA

For implementation of six sigma quality, in the first instance, it is imperative to identify the characteristics for which six sigma levels has to be maintained. The following strategy is being used at NFC.

- Identifying the customer needs.
- Analysing the present process.
- Improving the process.
- Consolidating the improvements.

3.1 Identifying the customer needs

Determination of customer needs form the first and most important step. To identify the same, it is essential to study product failures and areas of non conformance. The post irradiation studies attributed the fuel failures essentially to hydriding, pellet clad interaction, end-closure weld failure and debris. Thus for PHWR fuel, chemical purity, UO_2 weight, hydrogen content and endclosure weld integrity form the prime needs.

3.2 Analysing the present process

This step involves division of the entire manufacturing flow sheet into many process steps or various workstations. Process capability index, Cp., is determined for each parameter and workstation, to assess the level of performance. Analysis is carried out to determine the workstations that contribute maximum defectives. The following methodology is adopted at various workstations for detailed analysis.

- Is the present equipment or process and manpower capable of meeting six sigma requirements?
- Can the operations be performed in a better manner?
- Can any of the steps be eliminated during operations?
- Any latest technologies, that can be incorporated to improve the process?

The analysis has revealed that the solvent extraction system used for purification of uranyl nitrate solution meets six sigma requirements and has a process capability index of 3.96 with respect to total boron equivalent. The present quality levels at various stages are shown in Table-1.

3.3 Improving the process

Process improvement is a continuos commitment. Quality improvement teams are formed by drawing members from production, quality, development and maintenance to overcome various problems within a time schedule. Statistical techniques like design of experiments, test of significance are used to identify the reasons for non-conformance. After the causes are identified, engineering solutions are evolved to overcome the deficiencies.

To improve the endclosure weld quality, it was decided to carry out industrial experimentation using orthogonal arrays to determine the factors that affected weld quality [3]. It was found that, pre- heat and weld- heat interaction, squeeze pressure, weld heat and quality of power source play an important role in determining weld quality. The studies lead to installation of dedicated power supply with narrow band of voltage, for carrying the welding operations. These modifications has resulted in improved weld quality as shown in fig.1

To provide greater assurance to the customer, the sampling procedures for metallographic evaluation were modified and subsequently a non-destructive, ultrasonic testing method was developed for evaluating end closure welds.

3.4 Consolidating the improvements

A comprehensive quality plan involving a series of on line and offline quality control measures are used to ensure the quality. The QA philosophy being followed at NFC is shown in fig.2. Prior to commencement of production, the machines are subjected to qualification trials, to verify process centring and product quality. During production, process is controlled by monitoring various parameters. Automatic controllers with feed back loops are employed for controlling the critical process parameters. The intermediate and the final product quality are evaluated by using various destructive and non-destructive techniques(Table.2). Random sampling is carried out to provide additional confidence.

A computerised documentation system enables to carry out trend analysis and provides necessary feedback for corrective action. The documentation also provides assurance to the customer regarding process and product quality levels.

4.0 FUTURE COURSE OF ACTION

To bring down the rejection levels further, computer aided manufacturing systems with complimentary Quality Information System are being developed. These in tandem with statistical process control will facilitate rapid and accurate methods of process control by providing immediate alert signals and subsequent fault diagnosis.

With a view to attain ' zero defect levels' the concept of intelligent processing of material is being developed. It employs non-destructive techniques to evaluate product characteristics while it is being made and then providing necessary corrective action through feedback loop to ensure that no defectives are produced. Trials are being carried out to characterise end closure welds by using acoustic emission and thermography.

Visual inspection that is associated with unavoidable inconsistencies is inevitable during fuel manufacturing. To overcome these deficiencies, machine vision systems involving both optical camera and laser based systems coupled with image analysis software are under development.

5.0 CONCLUSIONS

Process capability, Cp. greater than 2 has been achieved in following areas

- Chemical purity of UO2.
- Endclosure weld integrity.
- Hydrogen content
- Helium content in fuel elements.
- Dimensional specifications.

The decreasing trends of fuel failure rates in Indian PHWR's as shown in fig.3 vindicate our approach.

6.0 ACKNOWLEDGEMENT

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7.0 REFERENCES

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2. MIKE HARRY.J, "Six sigma : A breakthrough strategy for profitability ", Quality progress, May1998, pp.60-63.

3. NFC internal report," Optimisation of parameters for endclosure welding".

PRODUCT CHARACTERISTIC	C P (PROCESS CAPABILITY INDEX)
1. Chemical Purity of UO2	3.96
2. Hydrogen content	3.61
3. Endclosure Weld Integrity	3.11
4. Spacer pad weld strength	1.13
5. Bearing pad weld Strength	1.12
6. Helium Content	2.11
7. UO 2 Content in bundle	1.54
8. Zircaloy in bundle	1.26

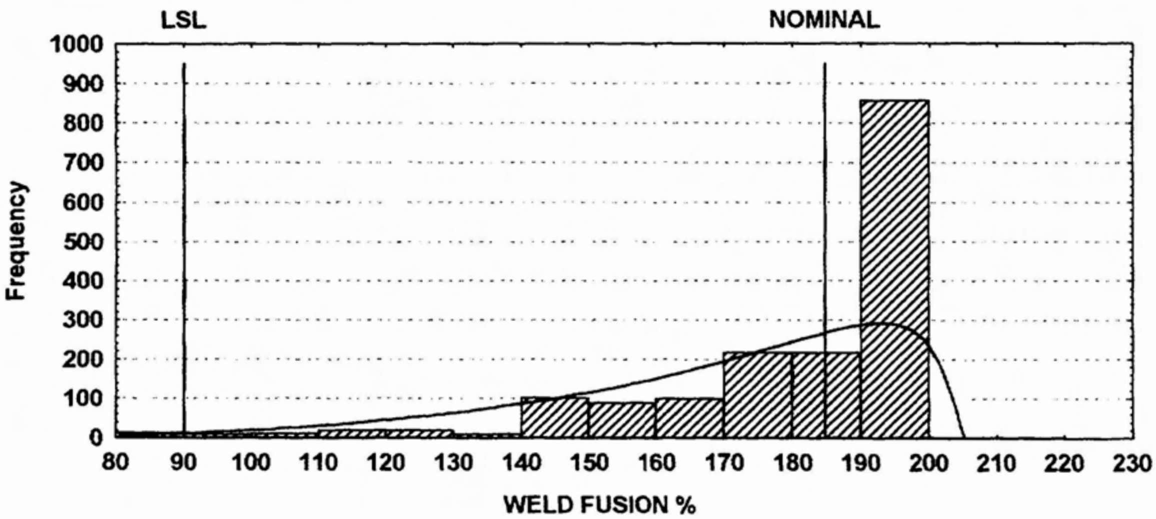
Table 1. QUALITY LEVELS AT VARIOUS STAGES

PREVIOUS

Sample size 1668 Mean: 184 % Sigma: 22.74

Specifications: LSL=90. Non-Normal Fit; Skewness: -1.9882 Kurtosis: 4.39901

Cpk=.8546 Cpl=.8546



RECENT

Sample size: 2148 Mean: 197.8 % Sigma: 6.08112

Specifications: LSL=90 %

Non-Normal Fit Skewness: -3.7255 Kurtosis: 19.0710

Cpk=2.261 Cpl=2.261

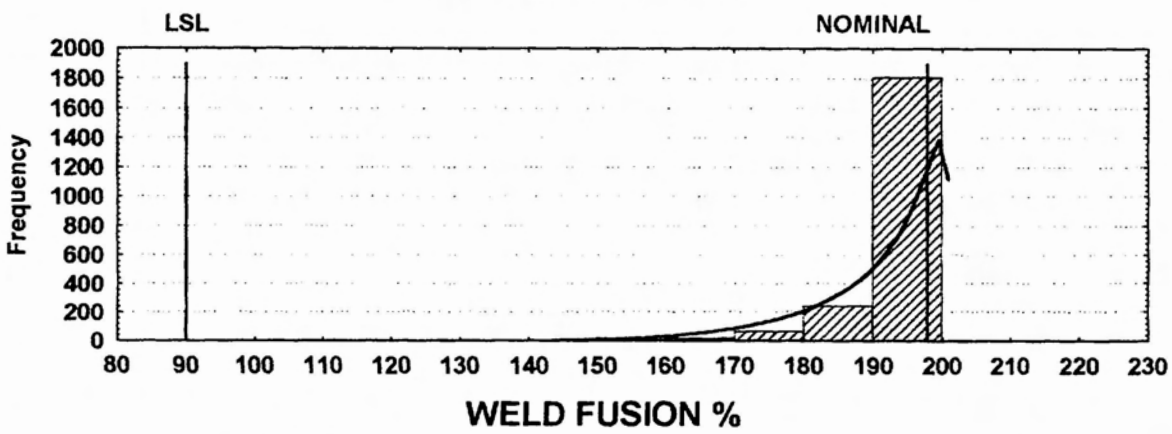


Fig 1. QUALITY LEVELS IN ENDCLOSURE WELDS

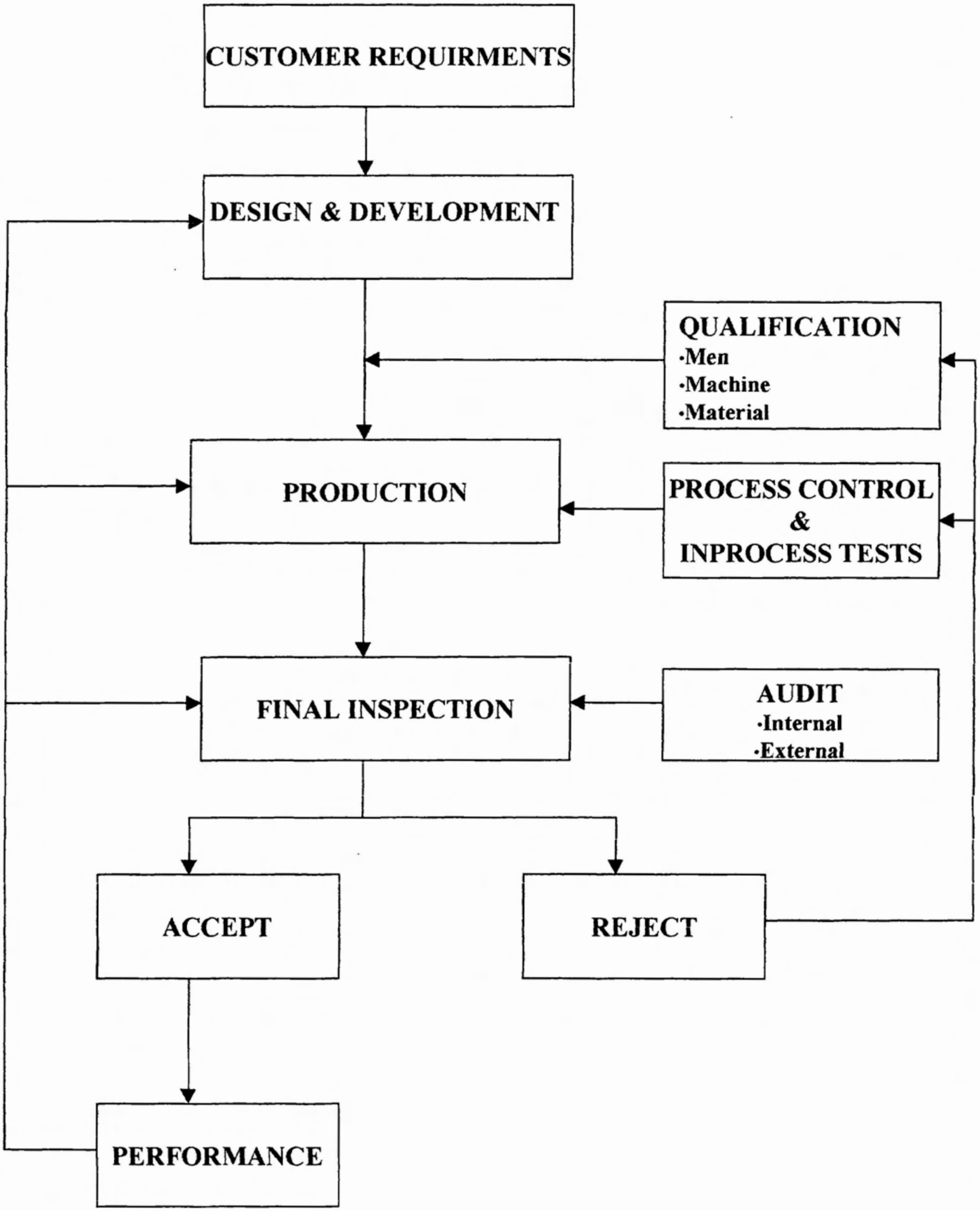


Fig 2. QA PHILOSOPHY FOLLOWED AT NFC

DESTRUCTIVE TESTS

TEST	APPLICATION
1. Wear test	Graphite coating
2. Metallography	Endclosure,Appendage & End plate welds.
3. Strength Testing	Appendage and End plate welds.

NON DESTRUCTIVE TESTS

TEST	APPLICATION
1. Beta Back Scattering	Graphite Coating thickness.
2. Ultrasonic testing	Endclosure Weld Evaluation
3. Helium leak testing	Fuel pins & bundle Integrity
4. Visual Inspection	At various stages

Table 2. LIST OF DESTRUCTIVE AND NON DESTRUCTIVE TESTS CARRIED OUT DURING PHWR FUEL FABRICATION.

Fig.3 PHWR FUEL FAILURE RATES